KIMBERLITE AT BACHELOR LAKE, QUEBEC

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ABSTRACT

Kimberlite forms small bodies intruding Keewatin-type rocks near Bachelor Lake in Lesueur Township, Abitibi-East County, Quebec. Most of it has porphyritic and panidiomorphic textures and consists of olivine and altered olivine, phlogopite, calcite, augite, perovskite, magnetite, ilmenite, apatite, and chlorite. Some of the calcite, which composes as much as 45 per cent of certain specimens, forms medium to fine anhedral grains sharply molded against or completely enclosing euhedral crystals of olivine, phlogopite, augite, perovskite, magnetite, and apatite in a manner strongly suggesting that it is a late-crystallizing primary mineral. The Bachelor Lake kimberlite is similar chemically, mineralogically, and texturally to some ultrabasic rocks of Paleozoic or younger age that occur at several localities in eastern North America. The recognition of this rock-type in northern Quebec has interest in respect to the problem of the provenance of some of the diamonds found in glacial drift south of the Great Lakes.

INTRODUCTION

Bachelor Lake is in Lesueur Township, Abitibi-East County, Quebec (Fig. 1) and may be reached most conveniently at present by means of aircraft based at Senneterre and Amos. The kimberlite occurs about three miles southwest of the Lake, near a zinc-lead-silver deposit owned by Dome Exploration (Quebec) Limited.

The geology of the area has been described briefly by Longley (1951) and by Graham (1950). The rocks exposed on the Dome property are mainly regionally metamorphosed Keewatin-type andesitic lavas, andesitic pyroclastics, and rhyolitic pyroclastics, which generally strike northeast and dip very steeply. These are intruded by a large body of olivine gabbro and gabbro and by many narrow, northwesterly-striking, vertical dikes of spessartite.

The kimberlite is in an area largely covered by glacial drift and it does not crop out. During the course of investigation of the zinc-lead-silver deposit, however, it was intersected by nine inclined diamond drill holes which were directed southeastward across a northeasterly-trending belt 1,800 feet long. It intrudes andesite and rhyolite-lapilli-tuff, which are carbonatized, but otherwise unaltered, immediately at the contacts. The relative positions of the intersections and of the outcrops of other rocks between drill holes and the orientation of contacts with respect to the drill core show that the kimberlite is not a continuous regular body and suggest, as a simple interpretation, that it, like the spessartite exposed nearby, forms northwesterly-striking steeply-dipping dikes a few feet wide.
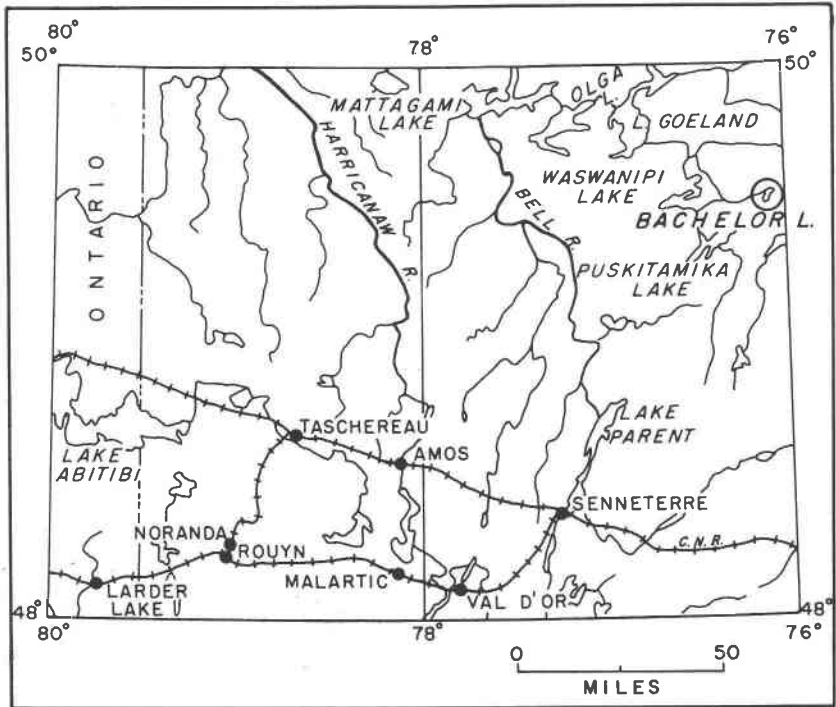
Fig. 1. Index map of northwestern Quebec showing location of Bachelor Lake.

Petrography

The kimberlite[1] is a medium to dark gray massive rock in which olivine and its pseudomorphs, phlogopite, calcite, and, in a few specimens,

[1] The name *kimberlite* was proposed by Lewis (1888, pp. 129–131) for a porphyritic peridotite composed of olivine and its alteration products, as well as bronzite, chrome diallage, smaragdite, biotite, perovskite, pyrope, ilmenite, chromite, and other minerals. The name *mica-peridotite* was proposed by Diller (1892, pp. 286–289) for a rock composed essentially of biotite, serpentine pseudomorphous after olivine, and perovskite with minor amounts of apatite, muscovite, magnetite, chlorite, calcite, and some undetermined secondary material. Through subsequent use, these names have gradually acquired somewhat broader meanings and at present they are regarded by some as synonymous (*e.g.* Williams, *et al.*, 1954, pp. 79–80). Others, however, have preferred to separate the kimberlites, which are porphyritic, from the plutonic periodtites (*e.g.* Martens, 1924, p. 313; Tröger, 1935, p. 297). In this paper, the rocks from Bachelor Lake are called kimberlite because their texture is dominantly porphyritic and their chemical and mineralogical compositions closely resemble those of some well-known kimberlites; rocks from other localities are called either mica peridotite or kimberlite depending on whichever one was used in the publication dealing with a particular locality.

ilmenite are clearly visible megascopically. The olivine and its pseudo-morphs, which are generally almost black, and the phlogopite, which is generally bronzy brown, tend to be euhedral. In some specimens they form abundant medium- to fine-grained phenocrysts in a dark gray, very fine-grained to aphanitic groundmass; in others, they are contained in a matrix rich in medium- to fine-grained white calcite; and in others, they show a complete gradation from medium to aphanitic thereby producing a seriate texture. The texture of the rock and the proportions of the various minerals discernible megascopically vary not only from one dike to another but also to some extent within individual dikes. The variations within individual dikes are erratic; reductions in grain size or in amount of phenocrysts are not evident megascopically along contacts or in narrow apophyses except within a millimeter or two of the contact. Veinlets of white calcite are common locally in several dikes.

Microscopically, panidiomorphic texture is conspicuous, for euhedral crystals are predominant not only among the large grains of olivine and phlogopite but also among the small ones and those of the minor constituents—augite, perovskite, magnetite, and apatite. Thus, according to the usage recommended by Knopf (1936, pp. 1748–1749) and followed by others, the kimberlite may be considered a lamprophyre. Poikilitic texture is also very noticeable in some thin sections. The host-crystals in most of these sections are calcite but in a few they are phlogopite. The calcite forms either anhedral grains up to a few millimeters across that completely enclose smaller euhedral crystals of other minerals, or optically continuous webs between closely spaced euhedral crystals. A few sections clearly show glomeroporphyritic texture caused by the arrangement of olivine crystals and, to a lesser degree, phlogopite in clusters. Microscopic study reveals that near the contacts of a dike, many of the phlogopite crystals are oriented with their major dimensions parallel to the dike margin. Elsewhere in the dikes, however, the structure is massive except for the subparallel orientation of flakes of phlogopite and laths of antigorite between some large crystals of olivine and phlogopite.

The mineralogical compositions of five representative specimens of the kimberlite determined by micrometric analyses of four thin sections of each specimen, are recorded in Table 1 in percentage by volume. The total amount of magnetite and ilmenite, exclusive of magnetite derived from olivine and of fine-grained ilmenite in perovskite, was measured in thin sections and the ratio of this ilmenite to magnetite was measured roughly in polished sections.

Olivine and pseudomorphs after olivine range in amount from 54 per cent by volume in one measured thin section to 24 per cent in another.

It forms euhedral and subhedral crystals ranging from about .05 to 10 mm. and lying mainly between .5 and 2 mm. in diameter. The composition of the olivine, based on measurements of nY and $2V$, is $Fo_{85}Fa_{15}$. Unaltered olivine was seen in only nine of the 53 thin sections examined and none was seen in specimens 1, 4, and 5 (Table 1). No relationship is evident between degree of alteration of olivine and amount of calcite present, for specimens 2 and 3 contain approximately the same proportion of fresh to altered olivine although they contain respectively the least and greatest amount of calcite. A transition from practically unaltered to completely altered olivine may occur in the width of a single thin section. In specimens 1 and 2 and several others, the altered olivine crystals consist of fine-grained aggregates of fibrolamellar and fibrous

TABLE 1. MINERALOGICAL COMPOSITION OF KIMBERLITE

	1	2	3	4	5
Olivine and altered olivine	48	45	29	38	41
Phlogopite	9	21	24	20	26
Calcite	18	13	39	20	17
Augite	—	0.2	0.1	6	1
Perovskite	3	7	1	1	3
Apatite	0.1	0.2	0.1	2	4
Magnetite	12	6	6	5	4
Ilmenite	7	4	1	—	3
Antigorite and calcite	—	—	—	7	—
Chlorite	3	4	—	—	1
Bowlingite (?), etc.	—	—	—	1	—

serpentine containing magnetite dust; in specimens 3, 4 and 5 and several others, they consist of aggregates of fine flakes and laths of yellow strongly birefringent bowlingite. A few specimens contain pseudomorphs after olivine that are composed of rims of bowlingite and cores of randomly oriented minute flakes of talc. One thin section, which contains some olivine crystals partly replaced by bowlingite, contains others completely pseudomorphed by fine-grained calcite and bowlingite. The distribution of the calcite in these pseudomorphs suggests that it has replaced olivine relics in grains that previously had been partly altered to bowlingite.

Phlogopite ranges in amount from 29 per cent by volume in one measured thin section to 6 per cent in another, but it constututes 20 to 25 per cent in most. Its crystals are euhedral and subhedral and are mainly .25 to 2 mm. in diameter although they range from about .01 to 10 mm.

Some optical properties of the phlogopite in the specimens of Table 1 are as follows:

	1	2	3	4	5
nY ($\pm$.005)	1.600	1.595	1.620	1.620	1.620
$2V$ (estimated)	5–10°	5–10°	15–20°	15–20°	15–20°
Dispersion	weak	weak	$v>r$ (strong)	$v>r$ (strong)	$v>r$ (strong)

These refractive indices show, according to the data of Winchell (1951, p. 374), that the phlogopites of specimens 1 and 2 have higher ratios of Mg to Fe than those of specimens 3, 4, and 5. The olivine in specimens 2 and 3, however, has properties that reveal no difference in the MgFe ratio. The phlogopite crystals in many specimens are distinctly zoned. They have parts in which the absorption and birefringence—Y and Z = medium brown, B = .045—indicate a lower ratio of Mg to Fe than in other parts in which the absorption and birefringence are lower— Y and Z = pale yellow, B = .030 (Winchell, 1951, pp. 374–375). In some specimens the zoning is normal, that is, the ratio of Mg to Fe decreases from core to rim; in others, it is reversed and commonly oscillatory.

The phlogopite crystals in most specimens have rims, partial rims, and irregular patches within them composed of a micaceous mineral that differs markedly from the phlogopite by having the following reversed pleochroism and absorption—X = deep orange brown, Y and Z = very pale yellow, almost colorless, $X>Y=Z$. These rims and patches have their cleavage traces and extinction positions parallel to those of the phlogopite crystal. The other optical properties nearly match those of phlogopite except for the birefringence which is about .010 higher in phlogopite. In most specimens the amount of this mineral is much less than one per cent but in one containing 20–25 per cent phlogopite, it constitutes almost 5 per cent of the rock. Reversed absorption and somewhat similar colors have been recorded for a highly manganiferous mica (Jakob, 1924, pp. 157–158), for the manganiferous mineral—ganophyllite —which is related to stilpnomelane (Winchell, 1951, p. 391), and for the mica-like mineral—astrophyllite (Winchell, 1951, p. 481). The other optical properties of the manganiferous mica and ganophyllite, however, are only approximately like those of the mineral in the kimberlite and those of astrophyllite are quite different. Mica with this abnormal absorption has been observed by others in kimberlite elsewhere and in the closely allied rocks, mica peridotite and alnöite (du Toit, 1907, p. 169;

Miser & Ross, 1923*a*, pp. 315–316; Miser & Ross 1923*b*, p. 277; Holmes, 1936, p. 383; Wagner, 1914, pp. 58 and 108; Martens, 1924, p. 311; Ross, 1926, p. 219; Singewald & Milton, 1930, p. 56). Wagner's book contains excellent photomicrographs (Plate XII) of lamprophyric kimberlite from South Africa which show rims of mica with abnormal absorption of cores of normal phlogopite in a relationship identical to that in the kimberlite from Bachelor Lake.

Calcite, which ranges from 12 to 45 per cent by volume in the measured thin sections, forms anhedral grains. Some of these are as much as 5 mm. across, others are only a few microns, but many are between .1 and 1 mm. Where calcite is abundant, it appears as a matrix in which dominantly euhedral and subhedral crystals of other minerals are embedded. In some specimens it is poikilitic and forms either anhedral grains completely enclosing smaller euhedral crystals of other minerals, or optically continuous webs a few millimeters across, between closely spaced euhedral crystals. In several specimens calcite appears to have slightly replaced phlogopite and, less commonly, olivine and clinopyroxene. In specimen 4, fine-grained calcite has partly pseudomorphed some of the antigorite laths. Some of the calcite in the kimberlite, however, shows no evidence of having originated by replacement of other minerals.

Clinopyroxene occurs in less than half of the thin sections, although it constitutes nine per cent by volume in one. It forms stubby euhedral or subhedral prisms and irregular granules which are visible only microscopically and are generally less than .1 mm. long. The clinopyroxene crystals tend to be clustered around the edges of olivine phenocrysts; some are partly included within the margins of the phenocrysts and others are enclosed within phlogopite. Most of the clinopyroxene is a pale brownish gray variety having the properties $Z \wedge c\ ca\ 45°$, $(+)\ 2V\ ca\ 60°$, and $r > v$ (distinct). This may be augite. In one specimen, a small proportion of the clinopyroxene is pale green but otherwise similar to the brownish gray variety. One section contains a small prism having the distinctive strong pleochroism, almost parallel extinction, and negative elongation of aegirine.

Perovskite[2] is a minor accessory in all specimens and reaches a maximum of seven per cent by volume in one measured thin section. It is included within phlogopite and calcite and in a few places, is molded on olivine. It forms equant grains that are mainly between .02 and .1 mm. in diameter. Many of these are euhedral to subhedral and rectangular or octagonal in cross section. The perovskite crystals are pale purplish brown or yellow; some are isotropic and others are weakly birefringent.

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[2] Optical identification confirmed by *x*-ray diffractometer.

The rims and cores of many grains are rendered almost opaque by an abundance of fine-grained ilmenite.

Apatite is also present in minor amounts in all specimens and reaches a maximum of five per cent by volume in one measured thin section. Most of its crystals are slender euhedral prisms .01 to .1 mm. long although a few are stout and attain lengths up to 5 mm. Some of the apatite prisms form groups that radiate into calcite from points of attachment on olivine crystals but most are entirely enclosed in calcite. A few small crystals show a zonal structure which may be similar to that of the skeletal crystals in South African kimberlite (Wagner, 1909, p. 551).

Magnetite occurs in all specimens and, excluding that formed by alteration of olivine, ranges in amount from about four to twelve per cent by volume. Nearly all specimens because of their abundant magnetite, are very noticeably magnetic. Most of the magnetite forms subhedral equant crystals which are mainly between .01 and .1 mm. in diameter. Many of these are included in phlogopite and calcite and a few are molded on olivine.

Ilmenite is present in most specimens and, exclusive of that at the margins of perovskite crystals, reaches a maximum content of seven per cent by volume. Most of it occurs as highly irregular anhedra, mainly .2 to 1 mm. in diameter, which contrast markedly in shape and size with the crystals of magnetite. Much of the ilmenite occurs interstitially among olivine crystals and some of it has phlogopite molded on it. Many of the anhedra are surrounded by wide irregular discontinuous rims of magnetite which apparently crystallized later than ilmenite. The large ilmenite grains contain widely spaced, thin yet persistent, lamellae of exsolved magnetite parallel to (0001). Some sections of specimen 3 contain no ilmenite but they show small areas apparently composed of very fine-grained leucoxene, talc, and bowlingite, surrounded by magnetite. These aggregates, which are roughly circular to hexagonal in outline might possibly be pseudomorphs after magnesian ilmenite or geikielite.

Antigorite, other than that obviously formed by alteration of olivine, is present in only a few samples. In specimen 4, in which it makes up seven per cent by volume, it forms laths mainly .1 to .3 mm. long which compose part of the groundmass and which commonly are partly or completely enclosed in phlogopite. Most of these are partly replaced by fine-grained calcite and some are completely pseudomorphed by it. Some of the laths consist of a single crystal of antigorite; others are composite and are composed in part of many small laths oriented with their long axes

perpendicular to a median cleavage trace running the length of the large lath. Some laths composed largely of calcite show a similar composite structure.

The origin of this antigorite is unknown. It may be a late primary mineral which has undergone partial carbonatization or it may be an alteration product of some pre-existing mineral. In the latter possibility, the original mineral may have been melilite for its composition would enable it to yield antigorite and calcite, its habit is commonly lath-like, and it commonly shows a combination of peg structure and a median cleavage trace reminiscent of the structure of the composite laths described above. Furthermore, melilite has been observed in kimberlite and mica peridotite elsewhere and is an essential constituent of the closely related rock, alnöite.

Chlorite forms rims only a few microns wide on phlogopite and mica with abnormal absorption in some thin sections. In addition, it is present as aggregates of minute ill-defined grains in the groundmass of several specimens and in one analyzed micrometrically (No. 2), it composes four per cent by volume.

Besides the minerals described above, pyrite and pyrrhotite were seen in small amounts in several polished sections and clusters of radiating fibers, which may be bowlingite and possibly some zeolite, are present in the groundmass of a few specimens and constitute about one per cent of specimen 4. In one drill hole, the rhyolitic rocks intruded by the kimberlite are cut by many narrow veinlets of fine-grained riebeckite, and a few groups of riebeckite fibers form small inclusions in the kimberlite within a millimeter or two of the contact.

CHEMICAL COMPOSTION

Chemical analyses and norms of three samples of kimberlite from Bachelor Lake are given in Table 2 and compositions of other kimberlites and a mica peridotite are included for comparison. Relative to other kinds of ultrabasic rocks, those in Table 2 are rich in TiO_2 and P_2O_5 owing to their high content of ilmenite and perovskite and of apatite. Although Nos. 1 and 2 contain more TiO_2 than the others in the table, they are not greatly abnormal, for the average mica peridotite of Daly (1933, p. 20) has 4.95 per cent TiO_2 and illustrations of some kimberlites show ilmenite and perovskite in great abundance (Williams, 1939, plate III). The CO_2 content of most of the rocks in Table 2 is extremely high.[3] Although No. 3 has a higher content than the rest, it is by no means unique, and, for example, it is surpassed in CO_2 content by a similar rock

[3] Kimberlites very rich in CO_2, which are common, were apparently excluded in compiling the averages (7 and 8).

TABLE 2. KIMBERLITE

	1	2	3	4	5	6	7	8
CHEMICAL ANALYSES								
SiO_2	22.74	24.15	22.86	26.16	26.20	28.83	35.02	36.33
TiO_2	5.86	6.46	2.98	2.50	3.60	5.67	1.22	1.89
Al_2O_3	3.09	2.58	3.78	3.79	11.34	2.94	3.90	5.09
Fe_2O_3	8.47	7.67	4.79	7.88	3.97	3.60	5.15	7.43
Cr_2O_3	0.09	trace	0.06	0.17	n.d.	n.d.	n.d.	n.d.
FeO	7.54	8.36	5.32	2.63	13.89	5.13	4.14	3.40
MnO	0.21	0.16	0.17	0.30	0.22	n.d.	0.06	0.10
NiO	trace	0.02	—	0.12	n.d.	n.d.	n.d.	n.d.
MgO	23.83	24.03	14.58	23.40	9.33	24.31	31.29	26.63
CaO	11.82	10.27	22.24	14.70	12.36	11.24	6.80	6.78
Na_2O	0.27	0.25	0.33	trace	0.67	0.75	0.34	0.37
K_2O	0.94	1.02	1.52	0.78	1.46	1.31	1.05	2.43
H_2O+	6.22	4.98	3.42	6.75	7.19	3.96	7.43	7.25
H_2O-	0.76	0.90	1.65	0.16	2.22	0.83	—	—
P_2O_5	0.68	0.23	1.32	0.86	1.40	0.77	0.87	0.66
CO_2	7.24	9.02	14.84	9.94	6.42	11.64	2.73	1.64
S	n.d.	n.d.	n.d.	—	0.48	n.d.	n.d.	n.d.
Total	99.76	100.10	99.86	100.14	100.51*	100.98	100.00	100.00
NORMS								
C	—	0.71	—	1.12	4.39	0.20	—	—
or	—	7.78	9.45	5.00	8.90	7.78	6.67	13.07
ab	—	2.10	2.62	—	5.76	6.29	2.62	—
an	4.17	—	4.45	4.73	11.95	—	5.84	5.00
lc	3.27	—	—	—	—	—	—	1.09
ne	1.14	—	—	—	—	—	—	1.70
kp	1.11	—	—	—	—	—	—	—
$CaSiO_3$	—	—	1.63	—	—	—	2.09	5.68
$MgSiO_3$	—	1.54	4.00	11.10	1.35	12.47	5.03	4.90
$FeSiO_3$	—	—	0.11	—	0.99	—	0.10	—
Mg_2SiO_4	42.07	39.51	23.17	33.18	15.61	27.86	51.22	43.19
Fe_2SiO_4	—	—	0.71	—	12.75	—	1.05	—
cs	1.29	—	—	—	—	—	—	—
mt	7.89	8.82	7.19	2.32	4.87	—	7.42	5.57
cm	0.22	—	—	0.22	—	—	—	—
hm	3.04	1.60	—	6.24	—	3.60	—	3.52
il	11.25	12.31	5.78	4.71	6.99	10.79	2.28	3.65
ap	1.68	0.34	3.02	2.02	3.36	2.02	2.02	1.68
pr	—	—	—	—	0.96	—	—	—
cc	16.60	18.20	34.40	22.60	14.80	18.00	6.20	3.70
$MgCO_3$	—	2.10	—	—	—	7.05	—	—
H_2O+	6.28	5.03	3.48	6.75	7.31	3.95	7.43	7.25
Total	100.01	100.04	100.01	99.99	99.99	100.01	99.97	100.00

1, 2, 3. Kimberlite, Bachelor Lake, Quebec; specimens 1, 2, and 3 in Table 1; W. H. Herdsman, analyst.
4. Kimberlite, Jagersfontein, Orange Free State (Williams, 1932, p. 246).
5. Kimberlite, Alnö area, Sweden; mode: pseudomorphs after olivine (serpentine, chlorite, and talc) 45.8%, biotite 28.4%, calcite 14.9%, perovskite 5.4%, apatite 3.4%, titanomagnetite 1.1%, pyrite 1.0% (von Eckermann, 1948, p. 102).
6. Mica peridotite, Fayette County, Pennsylvania (Kemp & Ross, 1907, p. 517).
7. Average of ten "basaltic" kimberlites (Nockolds, 1954, p. 1023).
8. Average of four "micaceous" kimberlites (Nockolds, 1954, p. 1023).
* Corrected for O equivalent of S (von Eckermann, 1948, p. 102).

from Pennsylvania that contains 17.5 per cent (Honess & Graeber, 1926, p. 6). Specimens 2 and 6 contain CO_2 in excess of CaO and thus it was necessary to calculate some of it as $MgCO_3$ in their norms.

CONCLUSIONS

An important problem posed by the kimberlite of Bachelor Lake is the origin of its plentiful calcite. This question is not peculiar to the Bachelor Lake rocks, however, for among kimberlites elsewhere, and mica peridotites and alnöites, carbonate-rich ones are very common indeed.[4] It is clear that the calcite in the kimberlite at Bachelor Lake is not a product of weathering, as was assumed to be the case in some similar rocks elsewhere, for the bedrock has been well scoured glacially and the drill cores are from depths of a few hundred feet or more below surface. It is unlikely, moreover, that the calcite is a product of hydrothermal alteration by fluids derived from a source distinctly younger than the kimberlite for carbonate is either absent or virtually so in thin sections of all the other rocks and the ores from the area. Thus, the conclusion seems inescapable that the calcite is a product of the kimberlite magma itself. Since carbonate rocks are unknown in the Precambrian section in this part of Quebec, no sound basis exists for postulating that the magma obtained its carbonate by reaction with limestone or dolomite.

Some of the calcite in the kimberlite at Bachelor Lake has undoubtedly formed by partial replacement of other minerals and that which occurs with antigorite as well-defined laths in specimen 4 may possibly have been derived from melilite. Some of it, however, shows no evidence of a secondary origin and it occurs as medium to fine anhedral grains sharply molded against or completely enclosing euhedral crystals of olivine, phlogopite, augite, perovskite, magnetite, and apatite in a manner strongly suggesting that it is a late-crystallizing primary mineral. It might be argued that such textural relationships could originate by selective replacement of a very fine-grained groundmass in preference to coarser phenocrysts by virtue of the greater reactivity of the finer material. If this were the case, however, one would expect that the resulting aggregate would inherit a fine-grained texture since this has happened where fine-grained andesite and rhyolite-lapilli-tuff have been carbonatized immediately adjacent to the dikes. The possibilities remain that the calcite originated by selective replacement of a glass groundmass or

[4] It is worth mentioning here that Sosman's experimental evidence on the low intrusion-temperature of peridotites, now widely considered in petrogenetic studies of ultrabasic rocks in general, is derived from a mica peridotite in Pennsylvania that contains a considerable proportion of carbonate (1938, p. 358).

of medium- to fine-grained *anhedra* of an unstable mineral such as melilite. However, since no evidence of these was seen in the 53 thin sections examined, these possibilities must be considered remote.

The tentative conclusion that some of the calcite in the kimberlite at Bachelor Lake is a late-crystallizing primary mineral differs with the conclusion of Shand (1947, pp. 444–445), Taljaard (1936, pp. 312–315), and Tröger (1935, p. 297) that the abundant calcite of South African kimberlite was derived from melilite formerly present in the rock. The suggestion made by Shand and Taljaard that South African kimberlites

	Primary		Secondary
Olivine			
Augite			
Ilmenite			
Phlogopite			
Magnetite			
Perovskite			
Apatite			
Calcite			
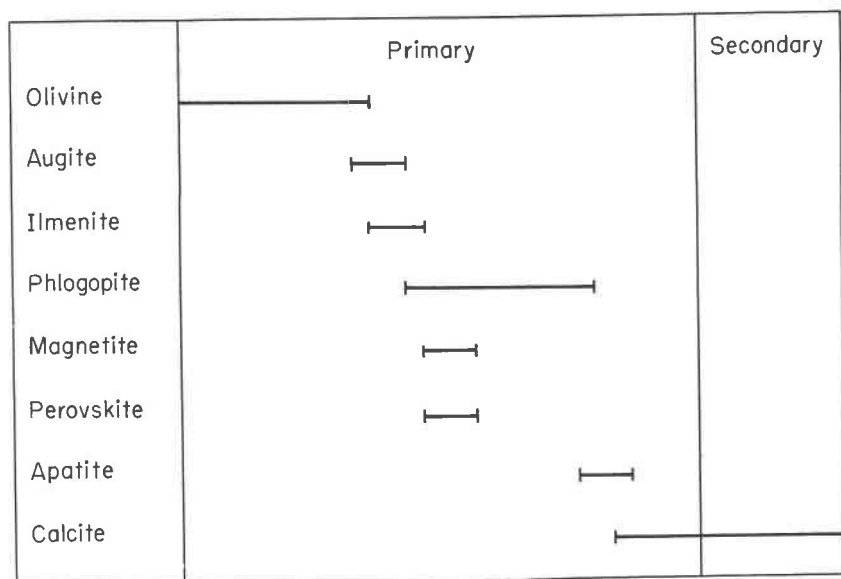
Fig. 2. Diagram showing paragenesis of primary minerals of kimberlite, Bachelor Lake.

are highly altered melilite basalts (olivine melilitites), may be applicable to the Bachelor Lake kimberlite, however, for chemically it resembles olivine melilitite in its high content of TiO_2 and P_2O_5 and in several other respects (*cf.* Nockolds, 1954, p. 1029) and it contains possible pseudomorphs after melilite in some specimens.

The sequence of crystallization of the primary minerals, inferred from their textural relationships, is given in Figure 2. The well-defined laths in specimen 4, now consisting of antigorite and calcite but perhaps originally consisting of melilite, formed before crystallization of phlogopite was completed.

This study of the kimberlite at Bachelor Lake has led to two geologi-

cal speculations. The first is concerned with the age of the intrusives. Figure 3 shows the distribution of mica peridotite, kimberlite, and alnöite in eastern North America. That it is legitimate to regard these rock-types as closely related is emphasized by the facts that the alnöites at some of these localities grade into mica peridotites or kimberlites by loss of melilite (Bowen, 1922, p. 6, p. 34; Harvie, 1909, p. 261, p. 275; Martens, 1924, pp. 310–314) and that the mica peridotite or kimberlite at other of
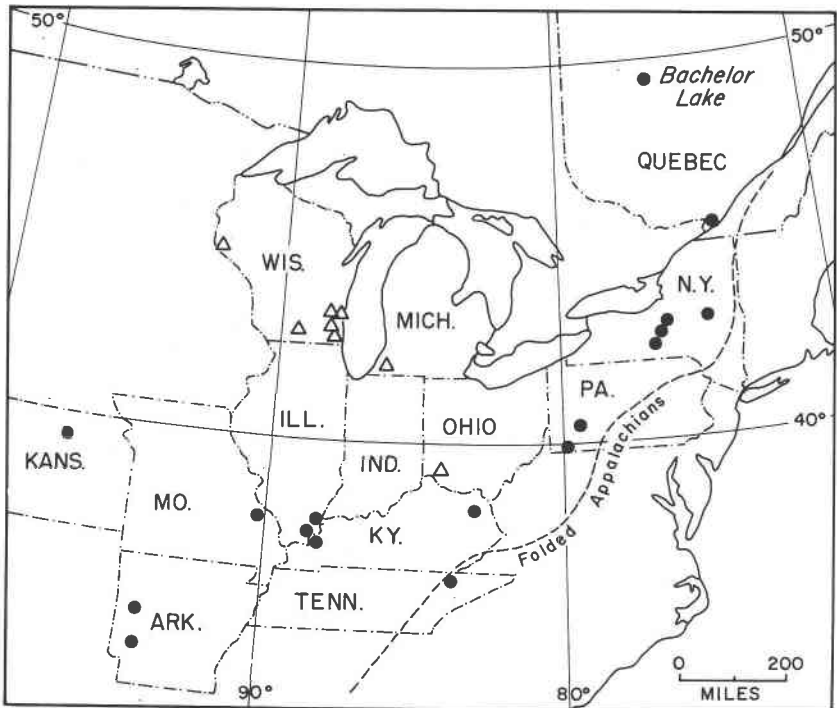
FIG. 3. Map of part of eastern North America showing locations of mica peridotite, kimberlite, and alnöite occurrences (black circles) and of some of the diamond discoveries in glacial drift (triangles). Data from Martens (1924), Tolman & Landes (1939), Hobbs (1899), and several other sources.

these localities contains melilite (Smyth, 1902, pp. 26–30; Williams, *et al.*, 1954, pp. 79–80). In all the places shown in Figure 3 with the exception of Bachelor Lake and Pike County, southwestern Arkansas, the ultra-basic rocks cut sedimentary rocks of Paleozoic age, the youngest rocks with which they are in contact. The mica peridotite of Pike County is early Upper Cretaceous for it cuts Lower Cretaceous sediments and has furnished material to the lower part of an Upper Cretaceous formation

(Ross, *et al.*, 1929, p. 189); the Monteregian intrusives of southern Quebec, to which the alnöites and mica peridotite plotted in Figure 3 belong, have recently been assigned by Clark (1952, pp. 109–110, p. 123) to the Cretaceous or early Tertiary. Although flat-lying limestone of Ordovician age crops out at Waswanipi Lake (Blake, 1953, pp. 16–18) shown in Figure 1, it does not extend eastward to Bachelor Lake, and hence its relationship to the kimberlite in unknown. The kimberlite at Bachelor Lake contains altered olivine and abundant calcite but it has not been metamorphosed either thermally or regionally. In view of this and particularly of the occurrence of similar rocks in eastern North America which are Paleozoic or later in age, the speculation that the kimberlite of Bachelor Lake may be younger than Precambrian merits consideration.

The second speculation deals with the provenance of the diamonds that have been found from time to time in glacial drift in Wisconsin, Illinois, Michigan, Indiana, and Ohio (the localities of some of these discoveries are shown in Figure 3). Interest in this problem has been displayed in Canada on various occasions and recently led Chubb to investigate a large crater in Ungava which now bears his name. In connection with this problem, it may be significant that more than 10,000 diamonds have been found in mica peridotite at Murfreesboro, Arkansas, one diamond has been reported in kimberlite near Syracuse, New York (Kraus & Slawson, 1947, p. 191), and diamonds have been recovered from alluvial gravels a short distance downstream from outcrops of mica peridotite in Union County, Tennessee (Hall & Amick, 1944, p. 429). Data plotted on the Glacial Map of North America (1945) suggest the possibility—proposed long ago by Hobbs (1899, pp. 386–388)—that some of the diamonds found in glacial drift south of the Great Lakes might have been moved from somewhere in northern Quebec. For this reason the recognition of a rock-type in northern Quebec, which is known to contain diamonds elsewhere in eastern North America, may be of some geologic interest.

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